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COGNITIVE AND PSYCHOMOTOR PERFORMANCE DURING NOAA OPS I AND II

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COGNITIVE AND PSYCHOMOTOR PERFORMANCE DURING NOAA OPS I AND II

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ADMINISTRATIVE INFORMATION

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ABSTRACT

Schmidt, T. C., R. W. Hamilton, Jr., G. Moeller and C. P. Chattin. 1974. Cognitive and psychomotor performance during NOAA OPS I and II. Tech. Mem. CRL-T-799. Tarrytown, N.Y.: Union Carbide Corp.

The NOAA OPS project developed excursion procedures for shallow nitrogen habitats. Operational verification of the concept was carried out in two laboratory saturation dives using three subjects each. Cognitive and psychomotor performance was evaluated on the subjects under several conditions: at sea level; during normoxic nitrogen saturation exposures of seven-day duration each at pressures equivalent to 30, 60, 90 and 120 feet of sea water (fsw); on compressed air excursions from saturation to depths as great as 300 fsw; and on equivalent air dives as made from the surface in the unsaturated condition. Results indicated that divers can live and work in normoxic nitrogen habitats--to depths as great as 120 fsw for at least one week duration--at performance levels comparable to sea level efficiency. Performance on compressed air excursions from saturation to depths as great as 250 fsw is significantly improved over performance on dives to the same depths as attained from the surface. This adaptation to narcosis appears to be a function of the depth of saturation, and perhaps of time spent at saturation.

Habitats/excursion diving/saturation diving/narcosis/adaptation to narcosis/performance

Introduction

NOAA OPS is the name given to a laboratory development program whose primary purpose was to design and test decompression tables and operational procedures for making vertical excursions from shallow habitats. The general operational and decompression aspects of this project are covered in a report on the project (Hamilton, et al., 1973). The work reported here was carried out during the NOAA OPS experiment.

The intent of this performance study was to assess objectively (by measurement of various cognitive and psychomotor functions) the adaptive effect afforded on compressed air excursions from the habitat to deeper depths, and the habitability of hyperbaric normoxic nitrogen environments for prolonged periods.

Hyperbaric air has long been known to cause a syndrome of impaired cognitive and psychomotor function. These effects are due primarily to the increased partial pressures of nitrogen; hence the term "nitrogen narcosis." The severity increases with increasing depth or partial pressure of nitrogen; intoxicating effects begin at approximately 100 fsw and few divers can work effectively beyond 200 fsw.

The degree of performance degradation due to narcosis is a function of the particular task being performed. It has been generally accepted that the degree of impairment increases with the complexity of the task being performed. Whereas certain studies have found that cognitive functions such as reasoning and short term

memory appear to be somewhat more sensitive than the motor functions (Kiessling and Maag, 1962; Adolfson, 1967), a more recent study (Moeller and Chattin, 1973) found that an adaptive tracking task proved sensitive to the effects of 7 atm air while two mental arithmetic tasks did not.

There is subjective evidence that frequent exposure to hyperbaric air--and thus raised partial pressures of nitrogen--affords considerable adaptation to its effects. Miles (1965) believes that at least weekly dives are necessary to maintain adaptation, and Bulenkov, et al. (1968) recommend that divers should make at least one chamber run to 7 atm per month, but reported observations from working dives to 9 atm (Lanphier, 1964) imply the susceptability may increase when the interval between dives is longer than one day.

The effect of adaptation upon mental performance in hyperbaric air has been objectively demonstrated (Shilling and Willgrube, 1937) but there have been no objective studies to date quantifying rates of adaptation (or unadaptation) for moderate to deep air diving. A study of intellectual capacity (Elcombe and Teeter, 1973) was done during a two-week normoxic nitrogen saturation at 100 fsw (PN_2 = 3.6 atm); no decrement in cognitive function of the subjects, as compared to that of the sea level control group, was found. In that study (Lambertsen and Wright, 1973) no physiological limitations to residence in hyperbaric nitrogen were seen.

Experiment

Two two-week laboratory saturations were conducted; the subjects were divers with moderate to extensive experience. In the first saturation (NOAA OPS I), the first week was spent at a habitat level of 30 fsw, and the second week at 90 fsw. In the second saturation (NOAA OPS II), the first week was spent at 120 fsw, and the second week at 60 fsw. Three diver-subjects occupied the habitat during each of the two saturations. The inert gas used throughout these experiments was nitrogen. The environment was normoxic at the saturation levels, while compressed air was used on all the excursions. Partial pressures of nitrogen at the various depths were 30 fsw =1.5atm, 60 fsw =2.4atm, 90 fsw =3.3atm and 120 fsw =4.2atm. Both upward and downward excursions were made; the compression rate used on the downward excursions was 100 fsw/min. Figure 1 illustrates the time-depth profiles of both experiments. Before the main saturation experiments, "bounce" dives from sea level pressure were made, to test laboratory systems, to rehearse experimental procedures, and to obtain reference physiological and performance data. Prior to these bounce dives the subjects had been given a moderate amount of training on the performance tests. The three performance tests used in this experiment were:

(1). Cognitive - paced arithmetic test

(2). Psychomotor - tracking task

(3). Manual dexterity - nut and bolt assembly test

Each series of three tests were designed to fit into a ten-minute performance package.

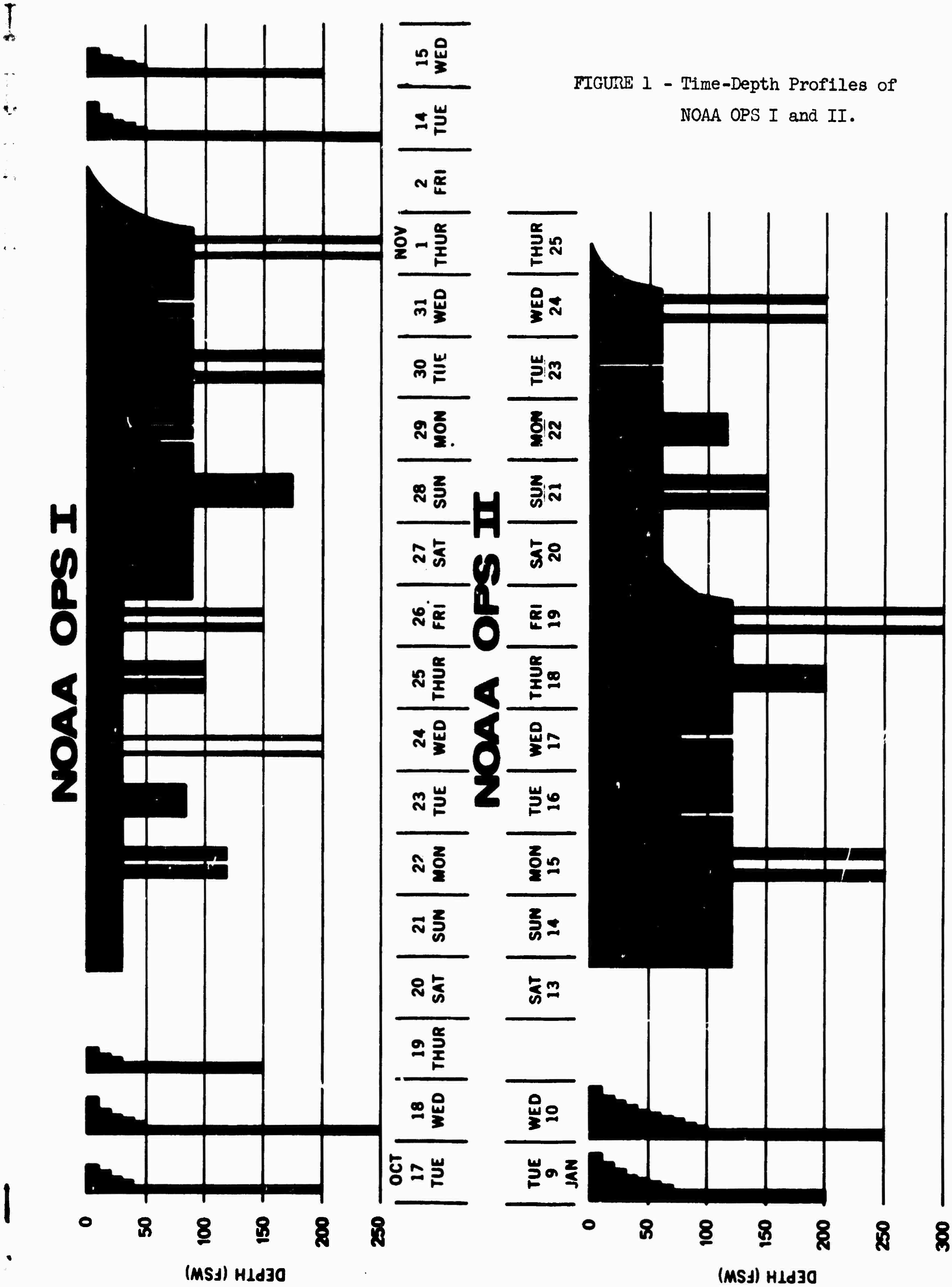

FIGURE 1 - Time-Depth Profiles of NOAA OPS I and II.

Paced arithmetic test

Timed arithmetic tests have always been useful measures of mental performance. The ordinary pencil and paper type of arithmetic test, whatever the calculation used, poses the problem in grading as to how to evaluate the score (number correct versus number attempted). The subject is never quite sure how much effort to spend in obtaining correct answers and how much to spend in working the greatest number of problems in the time allotted. Bennett has used arithmetic tests to assess narcosis on numerous occasions, and he reports both the number of problems attempted and the number correct, without really resolving the dilemma (Bennett, 1969). Ackles and Fowler (1971) suggested a "paced" arithmetic test which avoids the scoring problem. Problems are presented to the subject at a predetermined speed such that he can work about 80% of them. The subject is then presented the test at this same speed (usually about 3 or 4 seconds per problem) each time, and a single score is obtained which is independent of the subject's orientation, since he has only a fixed time for each problem and simply works correctly as many as he can.

The paced arithmetic test was administered to each subject by means of an automatic slide projector, the problems being projected onto a screen outside the chamber. They were easily and clearly visible to the subjects through the porthole. A timer (Lafayette Model 2303B3) was set to cycle the problems at a predetermined rate. The subject read the problems and wrote his answers on an answer sheet. Forty one-by-two digit multiplication

problems were used for each test. These were the same test sets used by Ackles and Fowler (1971) and by Hamilton (1973) in a similar application.

Each subject was tested before the experiment until an interval was established that resulted in a consistent score somewhere in the range of 70 to 90 percent correct. That sequencing interval was then used for all succeeding times the test was given. The rates at which the problems were presented to each diver, and the mean percent correct for each at sea level pressure are given in Table I.

Tracking

Manual tracking is a learned psychomotor skill and has been shown to be quite sensitive to environmental stress (Harris, 1970). Being a learned skill, it is also quite responsive to training. In an attempt to minimize the effects of learning on task sensitivity, the type of adaptive tracking espoused by C. R. Kelly (1967) was implemented. Here the term "adaptive tracking" refers to a task in which some parameter of the system is adjusted--e.g., becomes increasingly more difficult--through feedback to hold the average error within arbitrary limits. The adaptive tracking system used in these experiments was developed in the Human Factors Laboratory at the Naval Submarine Medical Research Laboratory, New London (Moeller and Chattin, 1973). The apparent amplitude and speed of target motion was varied directly with pursuit tracking accuracy; pursuit accuracy served as the performance measure.

TABLE I

The rates (seconds per problem) at which the arithmetic problems were presented to each diver, and the mean percentage of problems solved correctly for the pre-habitat condition.

DIVER	RATE (sec/prob)	PERCENT CORRECT
DJN	4.0	70
GJB	6.0	65
CAJ	2.5	92.5
BPU	1.9	77
CJ	2.5	69
PJB	3.5	77

From the subject's point of view, the task was pursuit of a complex two-dimensional periodic function. The target path appeared as a counter-clockwise circle, with periodic smaller inside loops. The circle amplitude (radius) varied directly with the tracking accuracy above or below a pre-set error limit, while period of rotation remained constant. In effect, tracking within the error limit produces an increase in the size of the target path and hence in target speed.

Pressure on the hand controller moves a follower dot (cursor) on the oscilloscope face in accordance with the standard control-display relationships. Both the target and cursor appear as simple dots on the oscilloscope, so the subjects have to track with a small separation between the two to maintain the visual identity of each. A voltage reading is automatically read and recorded--proportional to the distance between the target and cursor dot--every one-half second and integrated over a three minute period. The oscilloscope screen was located immediately opposite an eye-level porthole; the hand control was firmly mounted at a convenient level with an arm rest.

Nut and bolt assembly test

The nut-and-bolt test (Bennett Hand-Tool Dexterity Test) is a standard test used primarily for assessing the mechanical ability of job applicants, but it has been used successfully in diver performance studies as well (Bradley, et al., 1968; Hamilton, 1972). In performing the test, nuts, bolts and washers of different sizes are removed, relocated and retightened using wrenches and a screwdriver.

The test takes approximately four to six minutes to complete, and is scored on the total time to complete the task.

The test was administered according to the standard rules (Bennett and Fear, 1943), with the exception that the diver knelt, rather than stood, over the test frame. To begin timing the test, the diver flipped a toggle switch which activated a timer located outside the chamber; when he was finished, he again flipped the switch which stopped the timer. The total elapsed time was recorded in a log book by the investigator.

Results and discussion

In general, the divers exhibited significant adaptation to the increased partial pressures of nitrogen, both at "habitat" and on excursions to higher pressures. The day-by-day performance scores of each subject on each performance test are shown in Figures 2 to 6. Included in these figures are:

The daily control* scores for each environmental condition (dotted lines),

The linear regression lines based upon the daily control values (solid lines),

The mean and standard deviations of the daily control scores for each environmental condition (open circles with range marks), and

"Bounce" dive or excursion scores for any particular day (squares).

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*Control score refers to the mean daily scores of the subject on that test as performed in the appropriate pre-dive or pre-excursion "control" environment.

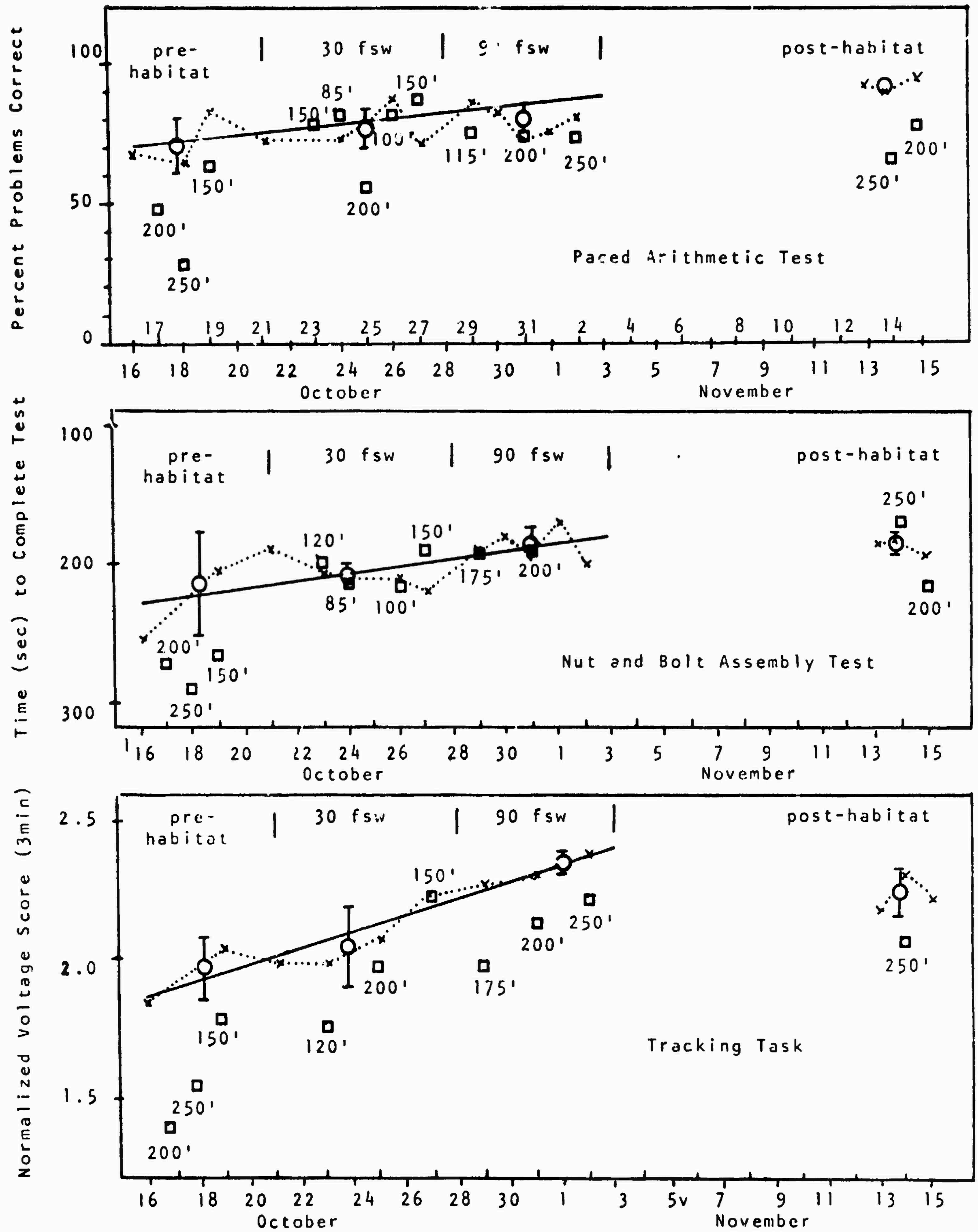

FIGURE 2 - Diver DJN: NOAA OPS I day-by-day performance.

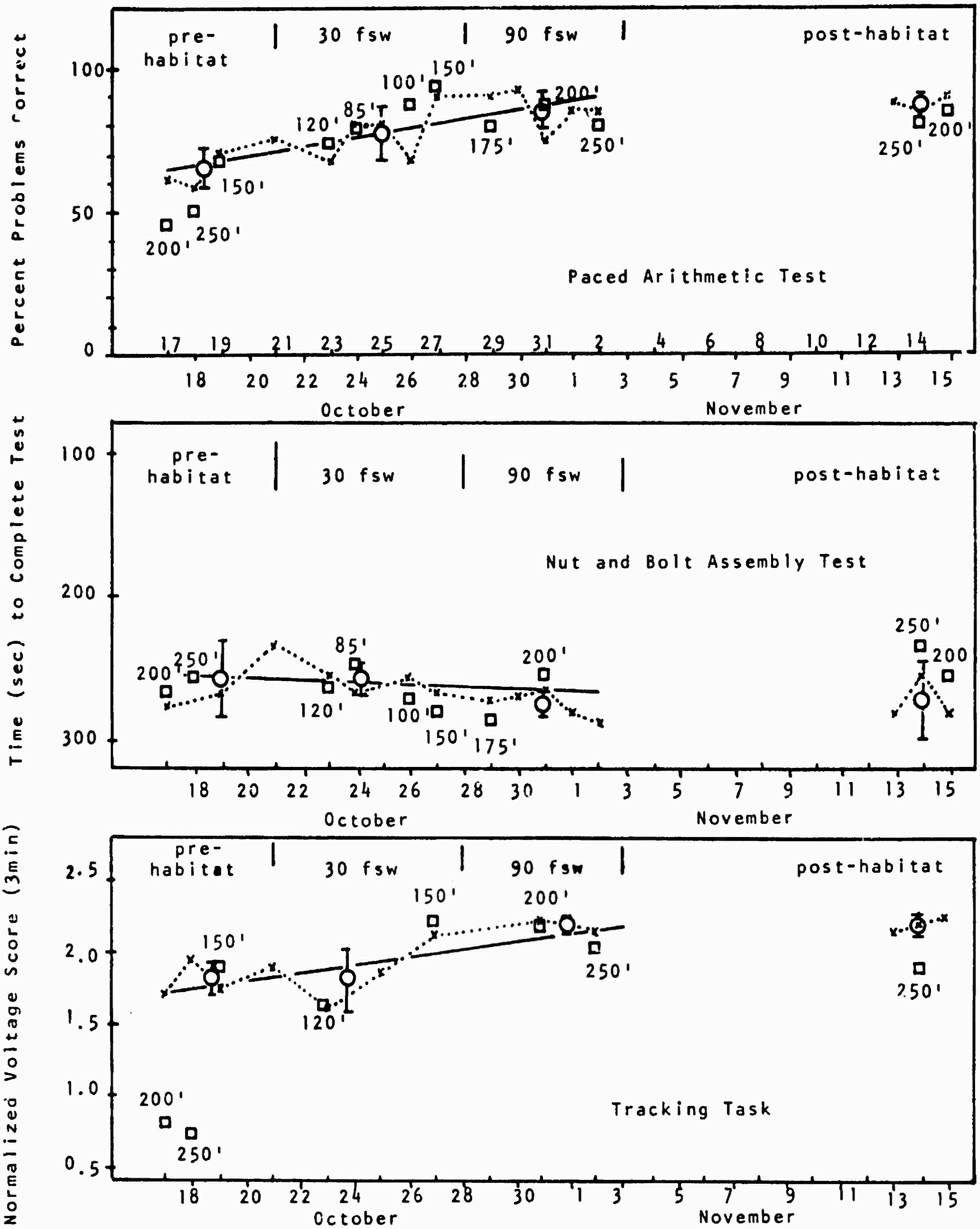

FIGURE 3 - Diver GJB: NOAA OPS I day-by-day performance.

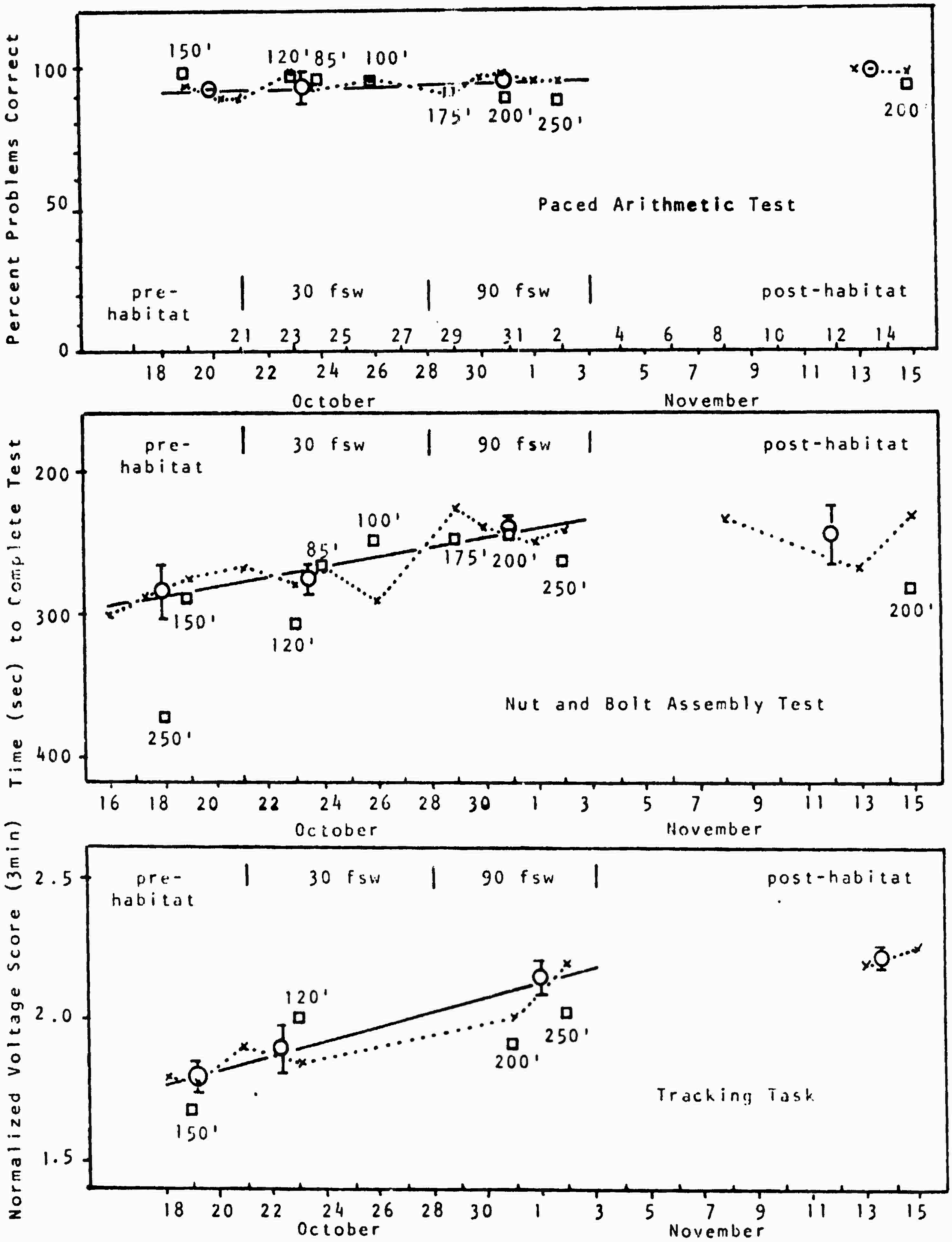

FIGURE 4 - Diver CAJ· NOAA OPS I day-by-day performance.

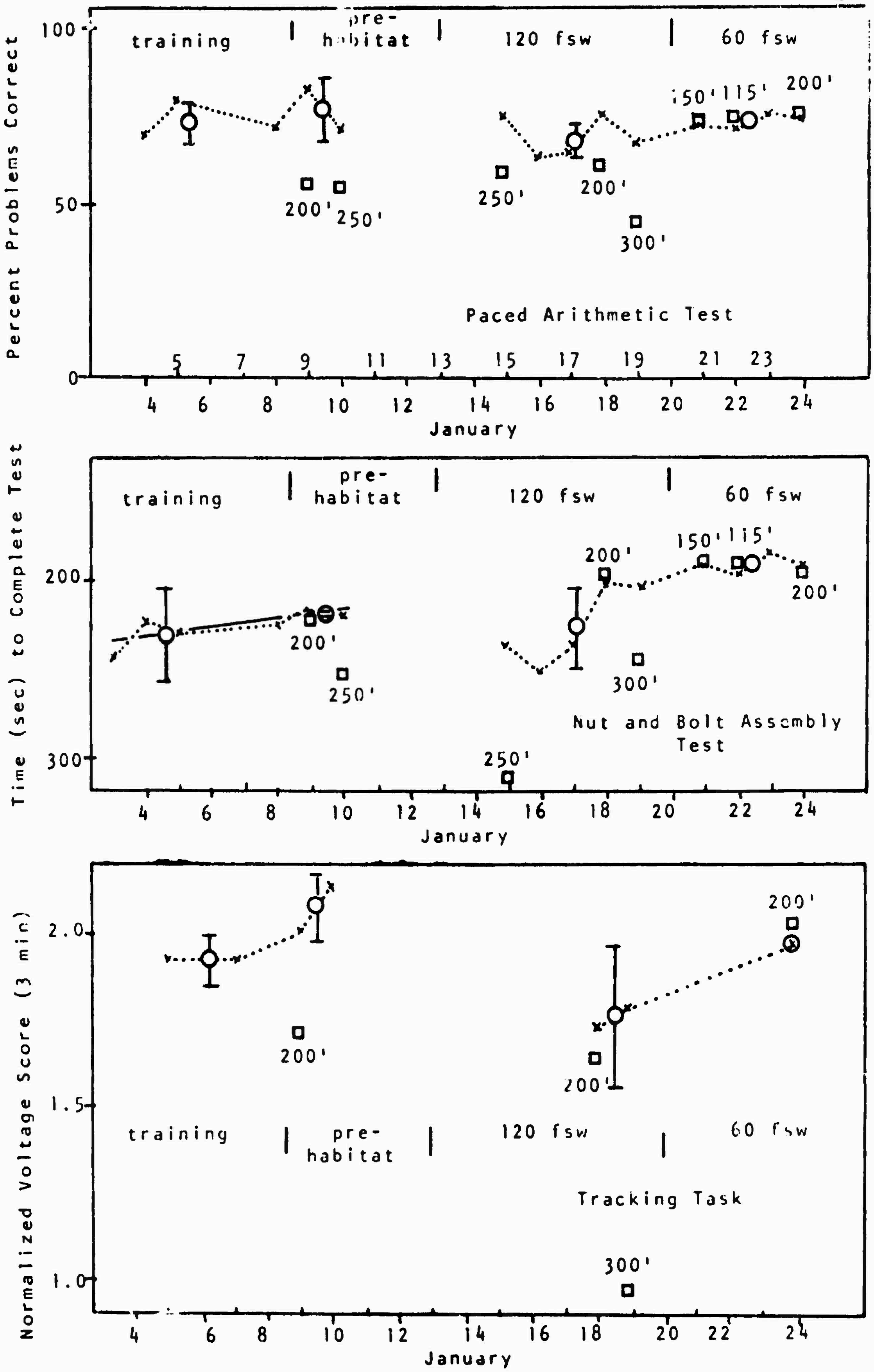

FIGURE 5 - Diver BPU: NOAA OPS II day-by-day performance.

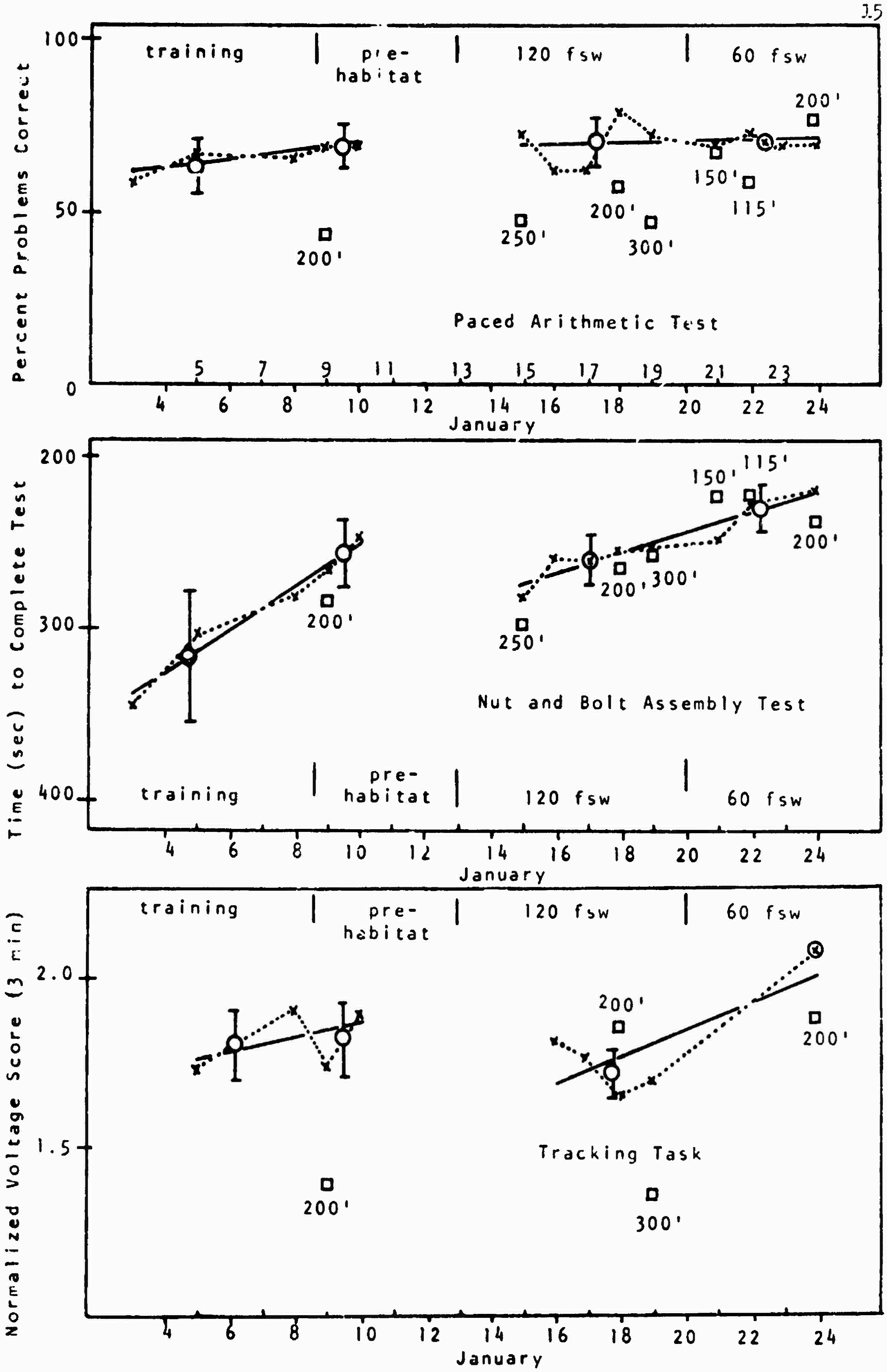

FIGURE 6 - Diver CJ: NOAA OPS II day-by-day performance.

In NOAA OPS I, the mean daily control scores for the pre-habitat, 30 fsw habitat, and 90 fsw habitat, can be fitted fairly well with a single linear regression line. The post-habitat scores are also shown. In NOAA OPS II, the mean daily control scores for training and pre-habitat conditions fit one linear regression line, and the 120 fsw habitat and the 60 fsw habitat conditions were found to fit another linear regression line. Diver PJB developed influenza during the early part of his residence at 120 fsw and was unable to make the excursions, and eventually had to be taken out of the chamber. He was replaced by diver GJB (a veteran of NOAA OPS I), who locked into the chamber for the one-week 60 fsw habitat. Consequently, data on only the other two subjects in NOAA OPS II were obtained.

Although direct learning effects as a variable were minimized as much as possible by training the divers to a reasonable level of profiency on each of the tests prior to the "bounce" dives and habitation, individual performance tended to improve linearly with time. The exception to this was the initial drop in performance during the initial exposure to the 120 fsw habitat, as compared to the pre-habitat scores. The performance scores from the earlier part of the 120 fsw habitat through the following two weeks also tended to improve linearly with time. Possible contributing factors were that all three divers in NOAA OPS II were slightly affected by influenza during the early part of the 120 fsw habitation, and there was a four-day break in the routine between the pre-habitat work and the 120 fsw saturation.

There was a continuing increase in performance scores with time. For this reason, performance scores on dives to equivalent depths done on different days were not directly compared to one another. Instead we computed percent changes in performance between the "adjusted" daily control value (as obtained from the solution of the linear regression equation for that particular day) and actual performance at increased pressure for that particular day. In the case of the post-dive scores, the percent changes in performance was determined from the difference between the scores at pressure and the mean post-habitat control score.

When these relative percent changes in performance are plotted vs. depth, curves resembling typical dose-response curves are obtained. In most cases there was a change in the dose-response relationship such that the performance decrement with depth was most severe for the pre-habitat condition, while the dives to equivalent depths from saturation resulted in significantly less change in performance. Changes in performance with depth for one diver are shown in Figure 7.

Changes in performance for each test were averaged over all the divers at 200 fsw, 250 fsw and in some cases 300 fsw; these are shown in Figure 8. This figure suggests that all the habitat levels of nitrogen resulted in adaptation to the effects of hyperbaric air, in comparison with performance at the same depths during dives from sea level. (No dives to 300 fsw from the pre-habitat condition were made). These results can be interpreted as evidence that exposure to increased nitrogen levels for extended periods can result in substantial adaptation to the effects of compressed air

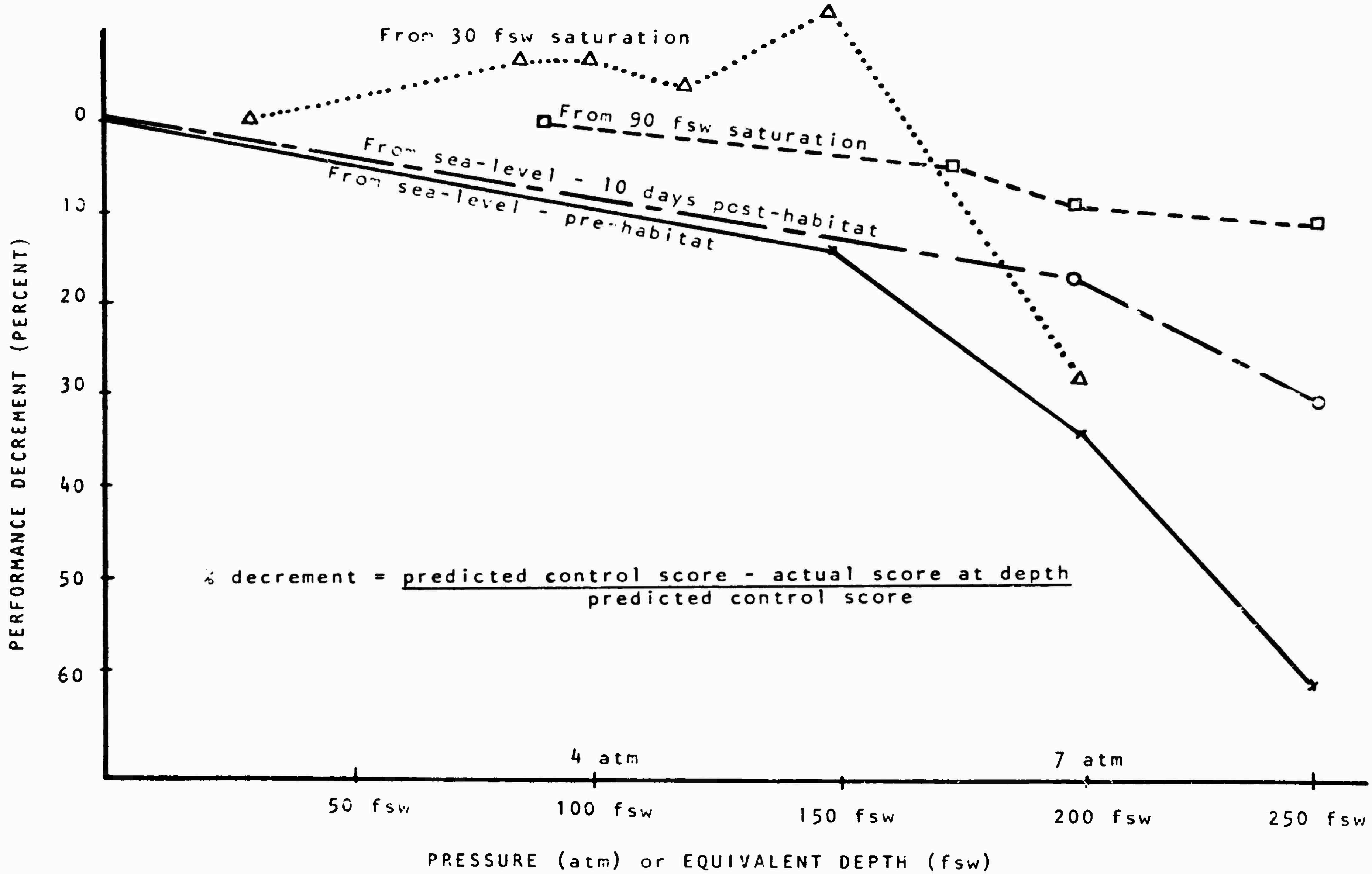

FIGURE 7 - Diver [illegible]JH: Dose-response curves showing percent decrement in performance on the paced arithmetic test. The greatest response is seen in the pre-habitat scores. Some improvement is seen with training (e.g. post-habitat) and a significant reduction in response is seen on adaptation at 90 fsw.

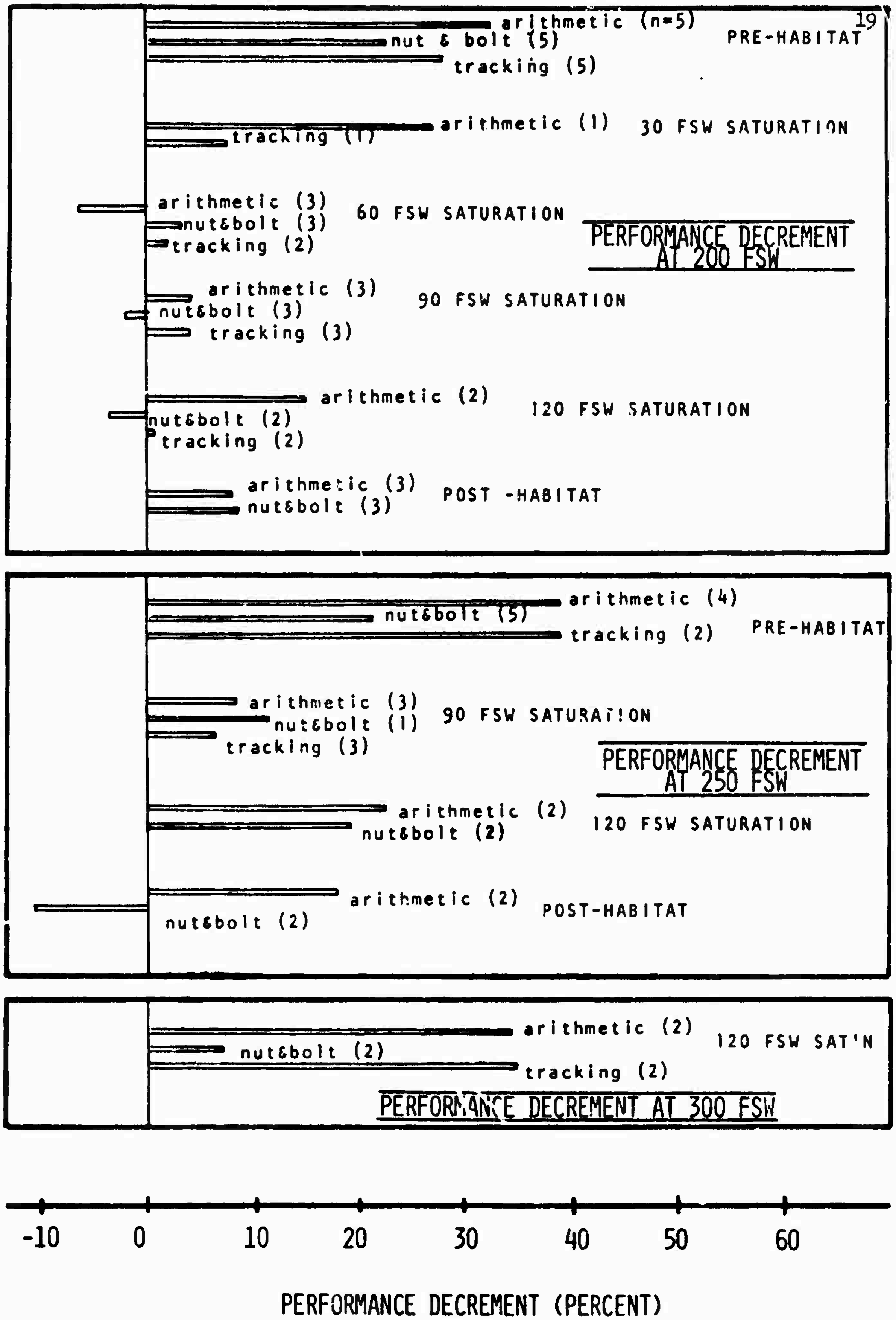

FIGURE 8 - Percent decrement for each performance test averaged over all the divers at 200 fsw, 250 fsw, and 300 fsw, as attained from various control conditions. (n=diver population).

on subsequent excursions.

The 90 fsw habitat could be expected to afford greater adaptation on deeper dives than the 30 fsw habitat, as it did, but our results suggest that adaptation at 60 fsw was greater than during the preceeding 120 fsw habitat. This may indicate that the adaptation seen was a function of time and training as well as depth. However, data from the 120 fsw habitat must be viewed with caution since the divers were in various stages of influenza, and no positive conclusions as to this effect can be made. This is particularly unfortunate, since this experiment represents the deepest saturation exposure to hyperbaric nitrogen which has been made.

In general, the test sensitivity to narcosis, in order of decreasing sensitivity was; paced arithmetic (cognitive), tracking (eye-hand coordination and vigilance), and the nut and bolt assembly test (simple motor coordination). However, this order of sensitivity was not necessarily binding for each individual diver. CAJ proved least sensitive to the arithmetic test and most sensitive to the nut and bolt test, and GJB was most sensitive to the tracking test and insensitive on the arithmetic and nut and bolt test. In this regard, CAJ was an engineering student and demonstrated a remarkable ability to make rapid, almost automatic, mental calculations, which was not affected by narcosis. Likewise, GJB had been working as a mechanic in the lab and was quite used to using hand tools and manipulating nuts and bolts. As to his insensitivity on the arithmetic test, he had such difficulty with the problems that they had to be presented to him at a rate that was slow enough for him to practically "work them out by hand" and was effectively

unchallenged by the test. These results indicate that rather than test sensitivity to narcosis being strictly dependent only on the specific functions involved, individual capabilities and innate task difficulty are also important determining factors.

Neurophysiological studies consisting of visual evoked responses and EEG's (Kinney et al., 1974) and somatic evoked responses (Langley and Hamilton, 1975) were performed during this dive series. Results indicated moderate--although not complete--neurophysiological adaptation.

Conclusions

1. Residence in normoxic nitrogen habitats over prolonged periods of one-week duration does not appear to result in any degradation of cognitive and psychomotor function. Rather, there is adaptation to its effects, convincingly at 90 fsw (PN_2=3.3 atm) and probably at 120 fsw (PN_2=4.2 atm).

2. Performance on compressed air excursions from habitats to depths as deep as 250 fsw (PN_2=6.8 atm) is significantly improved over performance on dives to the same depth as attained from the surface (pre-habitat).

3. Task sensitivity to narcosis is related to the subjects' individual capabilities and the innate task difficulty, as well as to the specific psycho-physiological functions involved.

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